Enhanced low-energy spin dynamics with diffusive character in the iron-based superconductor $(La_{0.87}Ca_{0.13})FePO$: Analogy with high T_c cuprates

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The recent discovery of superconductivity above 20 K in iron-based layered materials [1] has given rise to an avalanche of experimental studies, reminiscent of the early days of cuprate superconductors. In a recent paper [2], Nakai and coworkers reported on the NMR investigation of a related superconductor $(La_{0.87}Ca_{0.13})FePO$. This phosphorus-containing material has a T_c of 6 K, that is much lower than its arsenide-containing isostructural counterpart LaFeAsO. At odd with studies in LaFeAsO, Nakai *et al.* do not observed any signature of superconductivity in the NMR measurements. In particular, the spin-lattice relaxation rate of ^{31}P nuclei divided by temperature, $(T_1T)^{-1}$, shows a ω_{NMR}-dependent increase on cooling below T_c (ω_{NMR} is the NMR frequency). The authors indicate that to the best of their knowledge such increased low-energy spin dynamics have never been reported in the superconducting state and they suggest that these novel fluctuations could originate from a spin-triplet symmetry of the superconducting state.

In this short note, we show that the data of Nakai *et al.* actually bears strong similarity with two previous observations in cuprate superconductors: the divergence of the spin-spin correlation function at low frequency in $Tl_2Ba_2CuO_y$, and the absence of a superconducting-like response in the NMR measurements of $La_{2-x}Sr_xCuO_4$ with $0.06 \leq x \leq 0.12$.

In Fig. 1, we have plotted the value of $(T_1T)^{-1}$ measured at $T = 1.5$ K, as a function of ω_{NMR}, as extracted from the Fig. 5 of Nakai *et al.* [2]. $1/T_1$ clearly appears to be proportional to $\omega_{NMR}^{-1/2}$, a typical dependence for electronic spin diffusion in 1D systems, although the two-dimensional form $(T_1T)^{-1} \propto \ln(\omega^{-1})$ cannot be fully excluded at this stage (see the inset to Fig. 1). Spin diffusion corresponds to a situation where the spin-spin correlation function has an anomalous tail at long times (*i.e.* a divergence at low ω) [3]. The $\omega_{NMR}^{-1/2}$ divergence of low-energy spin fluctuations has been observed in one-dimensional spin chains (see references contained in recent works [4]).

The results of Nakai *et al.* are also reminiscent of a NMR study of $Tl_2Ba_2CuO_y$ by Kambe and coworkers [5]. In this high T_c cuprate, the occurrence of 2D spin diffusion was deduced from the experimental observation

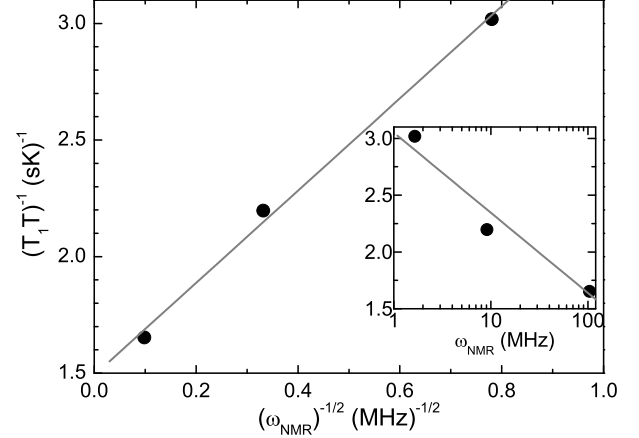*E-mail: marc-henri.julien@ujf-grenoble.fr

FIG. 1: Values of $(T_1T)^{-1}$ taken at $T = 1.5$ K, as a function of ω_{NMR} (Main panel) and a function of $\log(\omega_{NMR})$ (Inset). Data are taken from Nakai *et al.* [2] with $\omega_{NMR} = (1+K)\gamma H_0$, $K = 0.3\%$, $\gamma = 17.24$ MHz T^{-1} for ^{31}P and H_0=0.95, 5.25 and 60 kOe. Lines are linear fits to the data points.

$(T_1T)^{-1} \propto \ln(\omega^{-1})$, for both ^{205}Tl and ^{63}Cu nuclei, *even above T_c.* We note that, to the best of our knowledge, the exact nature of this diffusive process in a cuprate superconductor has not been elucidated yet.

Why 1D, rather than 2D, spin diffusion would be observed in the layered $(La_{0.87}Ca_{0.13})FePO$ is unclear, although this results immediately raises questions on the fascinating possibility of a (yet-undetected) symmetry breaking in the electronic ground state. It would be interesting to perform similar frequency dependent T_1 measurements in FeAs superconductors. The striped character of their (undoped) spin density wave state may evolve into quasi one-dimensional electronic correlations upon doping with charge carriers.

It is also worth considering another analogous situation: ^{139}La T_1 measurements in $La_{2-x}Sr_x$ CuO_4, with $0.06 \leq x \leq 0.12$ also show an enhancement on cooling throughout the superconducting state. This increase is due to the freezing of magnetic fluctuations on approaching the cluster spin glass transition [6]. In this case also, the occurrence of superconductivity is not detected in the NMR data. In $La_{2-x}Sr_xCuO_4$, the onset for the enhancement of $1/T_1$ does not usually coincide with the superconducting T_c, but both occur in a similar temperature range. It is thus also possible that $(La_{0.87}Ca_{0.13})FePO$ is close to a magnetic instability and that the enhance-

ment of $1/T_1$ occurs close to the zero-field T_c by chance. If magnetism is nucleated inside the vortex cores [7], the enhancement of T_1 could even start at T_c.

In conclusion, $(La_{0.87}Ca_{0.13})FePO$ displays an anomalous enhancement of spin excitations, with possible diffusive character, in its superconducting state. This findings points to an interesting similarity with some of the cuprate superconductors. The work of Nakai and coworkers should thus stimulate theoretical attention as well as more detailed NMR measurements at low T as a function of the frequency in these promising Fe-based superconductors.

Acknowledgment

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[1] Y. Kamihara, T. Watanabe, M. Hirano, and H. Hosono, J. Am. Chem. Soc. **130** (2008) 3296.

[2] Y. Nakai, K. Ishida, Y. Kamihara, M. Hirano, and H. Hosono, Phys. Rev. Lett. **101** (2008) 077006.

[3] H. Benner and J.P. Boucher in *Magnetic Properties of Layered Transition Metal Compounds*, ed. L.J. de Jongh, (Kluwer, Dordecht, 1990), p. 323, and references therein.

[4] M. Takigawa, T. Asano, Y. Ajiro, M. Mekata, and Y. J. Uemura, Phys. Rev. Lett. **76**, 2173 (1996); P. Carretta, A. Vietkin, and A. Revcolevschi, Phys. Rev. B **57** (1998) R5606.

[5] S. Kambe, H. Yasuoka, A. Hayashi, and Y. Ueda, Phys. Rev. Lett. **73** (1994) 197.

[6] See references in M.-H. Julien, Physica B **329-333** (2003) 693 and V. F. Mitrović, M.-H. Julien, C. de Vaulx, M. Horvatić, C. Berthier, T. Suzuki, and K. Yamada, Phys. Rev. B **78** (2008) 014504.

[7] B. Lake, G. Aeppli, K. N. Clausen, D. F. McMorrow, K. Lefmann, N. E. Hussey, N. Mangkorntong, M. Nohara, H. Takagi, T. E. Mason, and A. Schrder, Science **291** (2001) 1759.